Diffractive ρ production with an AdS/QCD holographic wavefunction for the ρ meson

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Abstract. We report on the results of our recent research published in [1] that shows that AdS/QCD generates predictions for the rate of diffractive ρ-meson electroproduction that are in agreement with data collected at the HERA electron-proton collider [2, 3]. Preliminary results of this research were presented in [4].

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INTRODUCTION

We demonstrate another success of the AdS/QCD correspondence [5, 6, 7, 8] by showing that parameter-free AdS/QCD wavefunctions for the ρ meson lead to predictions for the rate of diffractive ρ meson production ($\gamma^* p \to \rho p$) that agree with the data collected at the HERA ep collider. To compute the rate for diffractive ρ production, we use the dipole model of high-energy scattering [9, 10, 11, 12] in which the scattering amplitude for diffractive ρ meson production is a convolution of the photon and vector meson $q\bar{q}$ light-front wavefunctions with the total cross-section to scatter a $q\bar{q}$ dipole off a proton. QED is used to determine the photon wavefunction and the dipole cross-section can be extracted from the precise data on the deep-inelastic structure function F_2 [13, 14]. This formalism can then be used to predict rates for vector meson production and diffractive DIS [15, 16] or to to extract information on the ρ meson wavefunction using the HERA data on diffractive ρ production [17, 18]. Here we use it to predict the cross-sections for diffractive ρ production using an AdS/QCD holographic wavefunction for the ρ meson proposed by Brodsky and de Téramond [19]. With this AdS/QCD wavefunction, we also predict the second moment of the twist-2 Distribution Amplitude of the longitudinally polarized ρ meson. We find good agreement with Sum Rules and lattice predictions.

AN ADS/QCD HOLOGRAPHIC WAVEFUNCTION

The AdS/QCD wavefunction is given by [1, 19]

$$\phi(x,\zeta) = N\frac{\kappa}{\sqrt{\pi}}\sqrt{x(1-x)}\exp\left(-\frac{\kappa^2\zeta^2}{2}\right)\exp\left(-\frac{m_f^2}{2\kappa^2 x(1-x)}\right) \tag{1}$$

where N is a normalization constant and m_f is the light quark mass.[1] In Eq. (1), $\zeta = \sqrt{x(1-x)}b$ where x is the light-front longitudinal momentum fraction of the quark and b is the transverse separation between the quark and antiquark. ζ is the variable that maps onto the coordinate z in the fifth dimension of AdS space [19]. The parameter $\kappa = M_\rho/\sqrt{2} = 0.55$ GeV [1].

This AdS/QCD wavefunction is rather similar to the original Boosted Gaussian (BG) wavefunction discussed in [20, 15]

$$\phi^{\mathrm{BG}}(x,\zeta) \propto x(1-x)\, \exp\left(\frac{m_f^2 R^2}{2}\right) \exp\left(-\frac{m_f^2 R^2}{8x(1-x)}\right)\, \exp\left(-\frac{2\zeta^2}{R^2}\right) . \tag{2}$$

If $R^2 = 4/\kappa^2$ then the two wavefunctions differ only by a factor of $\sqrt{x(1-x)}$, which is not surprising given that in both cases confinement is modelled by a harmonic oscillator [1]. In what follows we shall consider a parameterization that accommodates both the AdS/QCD and the BG wavefunctions:

$$\phi(x,\zeta) \propto [x(1-x)]^{\beta} \exp\left(-\frac{\kappa^2\zeta^2}{2}\right) \exp\left(-\frac{m_f^2}{2\kappa^2 x(1-x)}\right) . \tag{3}$$

The AdS/QCD wavefunction is obtained by fixing $\beta = 0.5$ and $\kappa = 0.55$ GeV where as the BG wavefunction is obtained by fixing $\beta = 1$ and treating κ as a free parameter.

The meson's light-front wavefunctions can be written in terms of the wavefunction $\phi(x,\zeta)$ [18]. For longitudinally polarized mesons,

$$\Psi^{L}_{h,\bar{h}}(b,x) = \frac{1}{2\sqrt{2}}\delta_{h,-\bar{h}}\left(1 + \frac{m_f^2 - \nabla^2}{M_\rho^2\, x(1-x)}\right)\phi_L(x,\zeta) , \tag{4}$$

where $\nabla^2 \equiv \frac{1}{b}\partial_b + \partial_b^2$ and h ($\bar{h}$) are the helicities of the quark (anti-quark) and for transversely polarized mesons,

$$\Psi^{T=\pm}_{h,\bar{h}}(b,x) = \pm[ie^{\pm i\theta}(x\delta_{h\pm,\bar{h}\mp} - (1-x)\delta_{h\mp,\bar{h}\pm})\partial_b + m_f\delta_{h\pm,\bar{h}\pm}]\frac{\phi_T(x,\zeta)}{2x(1-x)} , \tag{5}$$

where $be^{i\theta}$ is the complex form of the transverse separation, $\mathbf{b}$. We impose the normalization condition:

$$\sum_{h,\bar{h}}\int \mathrm{d}^2\mathbf{b}\,\mathrm{d}x\,|\Psi^{\lambda}_{h,\bar{h}}(b,x)|^2 = 1 , \tag{6}$$

where $\lambda = L,T$. This means we allow for a polarization dependent normalization (hence the subscripts on $\phi_{L,T}$).

[1] Here we shall take $m_f = 140$ MeV, which is the value used in the dipole fits to the deep-inelastic structure function, $F_2(x,Q^2)$ [18].

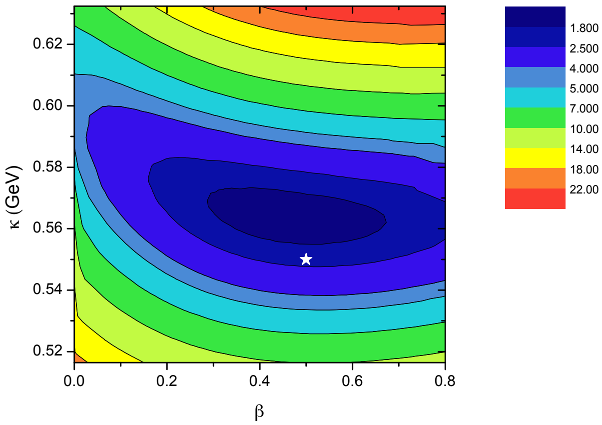

FIGURE 1. The χ^2 distribution in the (β, κ) parameter space. The AdS/QCD prediction is the white star.

COMPARISON TO DATA, SUM RULES AND THE LATTICE

We first compute the AdS/QCD prediction for the electronic decay width $\Gamma_{e^+e^-}$, which is related to the decay constant via

$$f_\rho = \left(\frac{3\Gamma_{e^+e^-} M_\rho}{4\pi\alpha_{\text{em}}^2} \right)^{1/2} .$$

Using

$$f_\rho = \frac{1}{2}\left(\frac{N_c}{\pi}\right)^{1/2} \int_0^1 \mathrm{d}x \left(1 + \frac{m_f^2 - \nabla^2}{M_\rho^2 x(1-x)} \right) \phi_L(x, \zeta = 0) \,, \tag{7}$$

we obtain $\Gamma_{e^+e^-} = 6.66$ keV, which is to be compared with the measured value $\Gamma_{e^+e^-} = 7.04 \pm 0.06$ keV [21].

To compute the rate for diffractive ρ production, we use the CGC[0.74] dipole model [13, 22] (see [18] for details), although the predicitions do not vary much if we use other models that fit the HERA F_2 data [14, 23]. The plots comparing the AdS/QCD predictions and the HERA data can be found in [1]. Here, in figure 1, we show the χ^2 per data point[2] in the (β, κ) parameter space (see Eq. (3)). It confirms that the AdS/QCD prediction lies impressively close to the minimum in χ^2. The best fit has a χ^2 per data point equal to $114/76$ and is achieved with $\kappa = 0.56$ GeV and $\beta = 0.47$. Note that the BG prediction i.e. $\beta = 1, \forall \kappa$, is clearly further away from the minimum in χ^2.

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[2] We include the electroproduction data and also the decay constant f_ρ in the fit.

We have previously shown [18] that the twist-2 Distribution Amplitude (DA) can be related to $\phi_L(x,\zeta)$ according to

$$\varphi(x,\mu) = \left(\frac{N_c}{\pi}\right)^{1/2} \frac{1}{2f_\rho} \int \mathrm{d}b\ \mu J_1(\mu b) \left(1 + \frac{m_f^2 - \nabla^2}{M_\rho^2 x(1-x)}\right) \phi_L(x,\zeta)\ . \tag{8}$$

To compare to predictions using QCD Sum Rules [24] and from the lattice [25], we compute the moment:

$$\int_0^1 \mathrm{d}x\ (2x-1)^2 \varphi(x,\mu)\ . \tag{9}$$

We obtain a value of 0.228 for the AdS/QCD wavefunction, which is to be compared with the Sum Rule result of 0.24 ± 0.02 at $\mu = 3$ GeV [24] and the lattice result of 0.24 ± 0.04 at $\mu = 2$ GeV [25]. The AdS/QCD wavefunction neglects the perturbatively known evolution with the scale μ and should be viewed as a parametrization of the DA at some low scale $\mu \sim 1$ GeV. Viewed as such, the agreement is good.

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